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In the figure, a line has been drawn through a succession of points which seem to suggest it. For this g/m increases per day (owing to the decrease of m) at a mean rate of $r = 0.00039$, which is equivalent to and air loss of 5×10^{-6} grams per day. Though it was formerly my opinion that the phenomenon could be completely explained in terms of the diffusion of air through water, the cusps (s) and subsequent intervals of relapse (r) when temperature increases, again do not bear this out. The whole is more complicated. The mechanism by which the air loss is brought about is largely solutional. Air is dissolved when temperature falls and is released from solution when temperature rises again. But for this the rate of increase of g/m throughout many months is in all the results remarkably constant and could be allowed for. Only at the beginning of the experiments with a new diver, and owing probably to gas adhering to the glass walls, are these mean rates irregular.

But the solutional effect in question under rapidly varying temperatures is fatal to the purpose for which the experiments were made. Though much of the discrepancy could be removed by placing the whole apparatus in an adequately constant thermostat, the outlook is not encouraging.

¹ Advance note from a Report to the Carnegie Institution of Washington, D. C. The work was done in deference to a request of President R. S. Woodward, that a variety of methods of the kind in question be looked into.

² *Carnegie Publications*, No. 185, Washington, 1913.

NOTE ON TORSIONAL MEASUREMENT OF VARIATIONS OF THE ACCELERATION OF GRAVITY BY INTERFERENCE METHODS¹

BY CARL BARUS

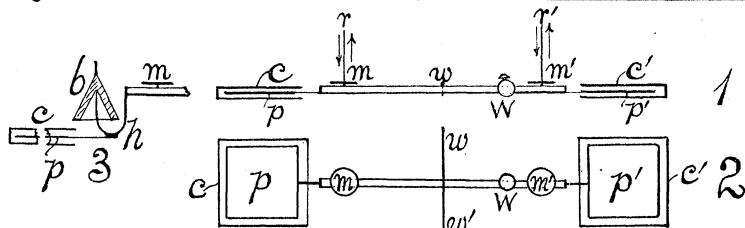
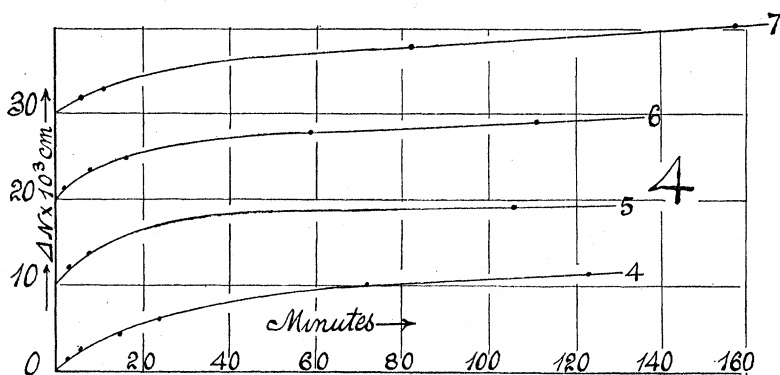
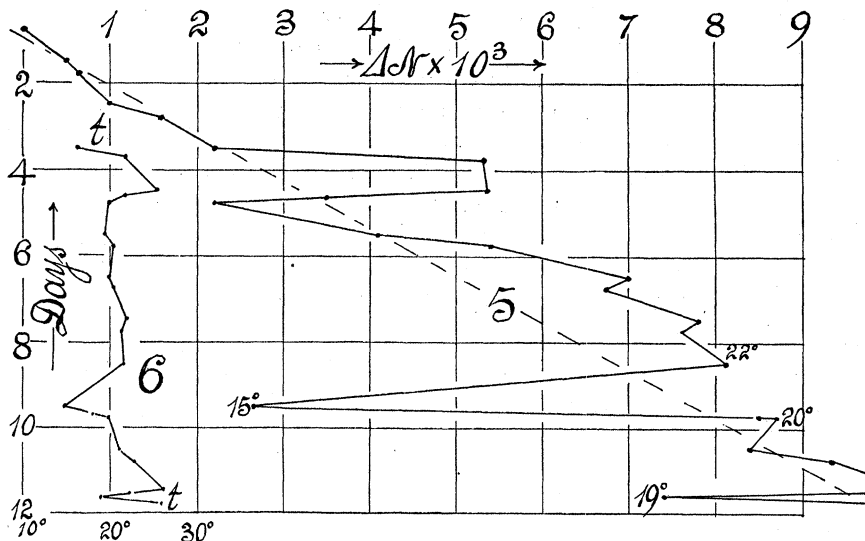
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1. *Apparatus*.—These experiments were undertaken to find in how far interferometer methods might contribute to the measurement of changes of g , under conditions in which the pendulum is inapplicable. The apparatus as a whole is a horizontal torsion balance with the deflection readable in terms of the displacement of the achromatic interference fringes. The method developed would be applicable in case of any ordinary chemical balance. The interferometer described admits of moderately rough handling; but it requires a level base, at least during observation. The mirrors are adjusted normally to a vertical plane, as the rays are in this direction.

Torsional weighing, by passing the counterpoise from pan to pan, is in itself a delicate operation when fringes are used. Moreover, the variation of viscosity is particularly large at the beginning. Nevertheless

my first observations were made with such an apparatus; and adequate air damping was secured by hanging the light scale pans in dash pots. Readings were made on a large graduated circle (torsion head), the stops of



which were micrometer tangent screws. Changes of twist registered by the interference fringes were evaluated either by the latter, or by the micrometer screw of the rectangular interferometer.

If the weight remains on one side, viscous deformation not only grows

indefinitely smaller and is subject to simpler equational conditions, but the apparatus itself may be made less cumbersome and steadier. Thus in figures 1 (elevation) and 2 (plan), r and r' are the two light rays of the interferometer. If w is the wire stretched between torsion heads (counterpoise W) and running normally to the balance beam, m , m' , the auxiliary mirrors of the interferometer attached to the beam, the latter may be prolonged and terminate in the thin metallic plates, p , p' . These are surrounded by the narrow glass cases c , c' , to secure air damping. This device is very efficient; and if c and c' are each placed on three leveling screws acting upward from below, while a stout vertical spring presses the cases downward from above (not shown), it is easy to free the plates p , p' , particularly as they may now also slide, with slight friction, on the leveling screws. Hence, as the beam is practically aperiodic, on putting a wide brass plate underneath the system $p m m' p'$ and close to it, no further casing is needed. The beam is thus easily accessible without opening the doors of a case. The fringes occasionally move, but they at once return to their equilibrium position, which is thus easily recognized. I tested this by removing the fixed counterpoise W , and proceeding with the method of weighing by exchanges. For this reason stiff hooks, h , figure 3, were fastened rigidly at each end of the beam, m . The plates p , p' , in c , c' , were soldered to the bottom of h as shown. The counterpoising weight, b , was bell shaped and reposed on the sharp point of the hook, h . A small projection on top allowed its easy removal with forceps. Adjusting the stops of the torsion head of the wire w , the bell weight b could be passed (with the requisite torsion) from one end of the beam to the other, without any inconvenience, the fringes in either case of adjustment appearing at once, in their proper position relative to the cross wire at the slit of the collimator. Of course, h must be stout enough to be free from flexure, relative to b .

Observations. Twists Alternately Opposite.—If the wire is too thin, the fringes are liable to wander. This ceases entirely with a wire 0.05 cm. thick, and about 35 cm. long, one-half of which is effective. It was of steel, hard drawn, but annealed to a blue temper to diminish the molecular instability. A weight of the order of 1 gram was selected and the double twist produced by this was $\Delta\theta = 50^\circ$. The weight was passed from end to end of the beam, counterpoised by torsion, without difficulty and the fringes set to coincide with the shadow of the cross wire on the slit. Great care had to be taken to avoid twisting the frame carrying the wire and torsion heads.

The constants of the interferometer being, angle of rays to mirrors, $i = 45^\circ$, breadth of the ray parallogram, $b = 10$ cm., micrometer displacement ΔN , we may write $\delta g/g = \delta\theta/\theta = \Delta N \cos i/b(\Delta\theta/2) = 0.16 \Delta N$ and as ΔN may be read to within 10^{-4} cm., the sensitiveness is about 10^{-5} , the gram counterpoise in question presupposed. The error to be

apprehended from viscosity may be estimated from the following observations, figure 4, of the yield of the wire (ΔN , vertical) with the gram excess at the end of the balance beam. The graphs shown are for the 4th to the 7th twists, alternately in opposite directions. The others, eleven in all, were similar. The curves show that if measurement is made within 3 minutes after twisting, the error from viscosity, if ignored, would not exceed $\delta g/g = 3 \times 10^{-4}$. If, however, the coefficient of viscosity is known and allowed for, the error of 3×10^{-5} is improbable.

If the graphs be used to compute the absolute viscosity of the metal for the given twist and diameter, it is found to increase in 100 minutes from about 4×10^{19} to 3×10^{20} and thereafter is nearly constant. The twist was about 1.4° per linear centimeter; but in alternating, the effect of this is about doubled.

Observations on the Permanently Twisted Wire.—The readings were made two or three times daily, as a rule, for over a month. They were adequately recorded in graphs like figure 5, for example, figure 6 being the corresponding temperature graph. As the twist produced by the excess of weight of about 1 gram was here also about 25° , we have $\delta g/g = 1.6 \times 10^{-4}$ for each of the divisions (10^{-3} cm.) of the scale. The laboratory temperature was very variable from day to day; and the effect of this on the graph is at first sight disconcerting, though it contributes essentially to the interpretation. In figure 5 the initial mean rate of yield referable to viscosity, may be estimated as $\Delta N = 0.0009$ cm. per day. This makes $\delta g/g$ vary 0.00014 per day, a quantity in itself too large to be used as a correction, with confidence; after a month, however, this nearly vanishes, but a much more serious consideration, the thermal variation of rigidity, remains. It is this feature which makes the graph so exceedingly jagged. If we take the large drop between the 8th and the 10th day to estimate this effect, the data would be: $t = 22^\circ, 15^\circ, 20^\circ$; $10^3 \Delta N = 8.1, 2.6, 8.7$ cm., which is equivalent to $\Delta N/\Delta t = 10^{-3}$ cm. per degree; or $\delta g/g = 2 \times 10^{-4}$, nearly, for each degree of fall of temperature promoting increased rigidity. Excellent observations on the torsional rigidity of iron and steel are given by Pisati (Landolt and Boernstein's tables). The coefficients are 2.1×10^{-4} for iron, and 2.3×10^{-4} for steel, therefore, even larger than the graph indicates. In fact, the present interferometer method could easily be modified to measure this constant accurately.

Summary.—In the above experiments as a whole, there is thus very little promise of arriving at the variations of g , with precision, by using torsional apparatus, so long as there is any marked change in the temperature of the environment. The discrepancy of the method is to be referred less to the viscosity of the metal and its thermal coefficient, than to the decrease of rigidity with rising temperature.

There is, however, one possible way out of the difficulty and this points

to the use of the alloys which Director C. E. Guillaume, of the Bureau International at Sévres, has spent so much time in perfecting. I shall hope to report observation with these in the future.

¹ Advance note from a Report to the Carnegie Institution of Washington, D. C.

THE GENUS *BOTRYCHIUM* AND ITS RELATIONSHIPS

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The genus *Botrychium* comprises about thirty-five species of almost world wide distribution. Up to the present our knowledge of the life history of these ferns has been confined almost exclusively to two species, *B. lunaria* (L.) Sw., and *B. Virginianum* (L.) Sw.

In 1910, Dr. H. L. Lyon¹ published a brief account of the embryo of *B. obliquum* Mühl, which differed so much from the two species mentioned, that he proposed to separate *B. obliquum* as the type of a new genus, *Sceptridium*.

Dr. Lyon made quite complete collections of material of this species, and also prepared series of microtome sections of the gametophyte and young sporophyte. This material, as well as similar material of some other species, was collected in the vicinity of Minneapolis.

Dr. Lyon very generously turned over this valuable material to me, so that I have been able to make a fairly complete study of the early development of this interesting species.

The gametophyte of *B. obliquum*, like that of the other species, is subterranean. It closely resembles in its general structure that of *B. lunaria*, and *B. Virginianum*, and in size is intermediate between them.

The mature gametophyte is a somewhat flattened tuber, 3-6 mm. in length and about half as wide. Upon the upper side is a more or less conspicuous median ridge upon which the reproductive organs, archegonia and antheridia are borne. These closely resemble those of the other species, but the spermatozoids are considerably larger.

The embryo differs remarkably from that of the other species. A very conspicuous suspensor is developed, which is wanting in the other species, and the relations of the first leaf and root are different.

The fertilized egg becomes much elongated, and forces its way downward into the tissues of the gametophyte before any cell-division occurs. The first division is transverse, and cuts off a large basal cell, which becomes the suspensor. The smaller terminal cell gives rise to the organs of the embryo-sporophyte.

The further development of the embryo is more like that of the Maratiales, especially *Danaea*, than it is like the other species of *Botrychium*.